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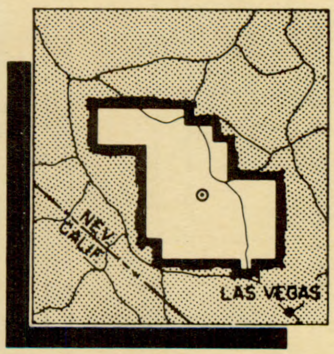
Operation TEAPOT

NEVADA TEST SITE

February – May 1955

Project 35.1

EFFECTS OF ATOMIC WEAPONS ON ELECTRIC UTILITIES



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CIVIL EFFECTS TEST GROUP

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The information contained herein was obtained from a test series conducted in 1955 and is related to the weapons then available. Specifically, these data are not directly applicable to thermonuclear weapons in the megaton yield range.

USAEC Division of Technical Information Extension, Oak Ridge, Tennessee

Report to the Test Director

EFFECTS OF ATOMIC WEAPONS ON ELECTRIC UTILITIES

By

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ABSTRACT

Duplicate electric-power installations consisting of transmission, substation, and distribution equipment were constructed in areas 4700 and 10,500 ft from Ground Zero (GZ) for use in Project 35.1 in the Apple II shot.

The test was made to determine the median survival range of the electric equipment; the extent of damage and the nature of the repairs required to restore disrupted service; and the ability of electric systems, in comparison to industrial plants and the residential communities they serve, to withstand the effects of an atomic explosion.

The damage was confined to the transmission and distribution circuits at the 4700-ft area and was of such a nature that the equipment could have been easily and quickly repaired. In the same area, typical homes were completely destroyed.

PREFACE

The electric companies of the United States, long used to restoring electric service after the damaging of equipment by hurricanes, floods, earthquakes, and other violent natural occurrences, have recognized the importance to the national defense of obtaining information on the effects of an atomic explosion on electric supply systems. As a public service, the Board of Directors of the Edison Electric Institute, an association of investor-owned electric-utility companies in the United States, approved a plan for the electric-utility industry to participate with the Federal Civil Defense Administration (FCDA) in the atomic tests in Nevada in 1955.

No doubt exists that the electric facilities, like all other service facilities, would be seriously damaged within a bombed area. Consequently it is important to determine the extent of damage to power lines, transformers, substations, and other installations beyond the area of total destruction. It is particularly important to determine the nature of repairs required to restore service in the fringe areas where homes, factories, and other establishments would survive sufficiently to permit occupancy and operation of electric equipment and to supply electric power for reconstruction projects following an atomic explosion.

ACKNOWLEDGMENTS

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Max M. Ulrich, Edison Electric Institute staff
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Arthur C. Werden, Jr., Southern California Edison Company
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ILLUSTRATIONS

Chapter 1

INTRODUCTION

1.1 GENERAL

The ability of electric supply systems to withstand the effects of atomic explosions and the related problem of rapidly restoring electric service to survival areas in the event of an atomic attack are of serious concern to both the Federal Civil Defense Administration and the electric-utility companies in the United States. Because of the lack of information on this subject, the Edison Electric Institute participated in a test (Project 35.1 of Operation Teapot) with the primary aim of obtaining information that would be of major importance to the national defense in the event of an atomic attack.

Although a limited amount of data is available on the effect of the World War II atomic explosions on the electric supply systems of Japan, there is no published information on the effect of such an explosion on typical electric supply systems in the United States, which are generally different in construction from those in Japan. Project 35.1 was the first test organized for the purpose of obtaining direct and specific information under controlled conditions on the absolute and relative effects that an atomic explosion would have on electric supply systems in the United States.

The electric equipment (Figs. 1.1 to 1.5) subjected to this test was representative of that which serves urban residential and commercial areas. It is listed as follows (the first two items in the list were also representative of the equipment that serves large industrial plants):

1. A 69-kv transmission line installed on steel towers (Fig. 1.6).
2. Substation equipment consisting of a 69-kv oil circuit breaker, stepdown transformers, and associated structures (Fig. 1.7).
3. Distribution substation equipment consisting of two 4-kv oil circuit breakers and voltage regulators (Fig. 1.8).
4. Approximately one-half mile of varied 11- and 4-kv distribution line construction on wood poles, including distribution transformers and secondaries (Fig. 1.9).

It was not considered necessary or feasible to expose a large generating station to the atomic explosion in this test. With the existing interconnections among utility systems, electric power could be transmitted to a stricken area from distant points if local generating facilities were destroyed or seriously damaged.

Since there was no outside source of electric power at the test site, it was necessary to use a 5-kw portable generator, which was driven by a gasoline engine, to energize a portion of the system secondaries during the explosion. It was considered that sufficient information concerning the effects during the shot on the electric system could be obtained from a postshot study of the energized secondaries and postshot testing of the entire system.

(Text continues on page 15.)

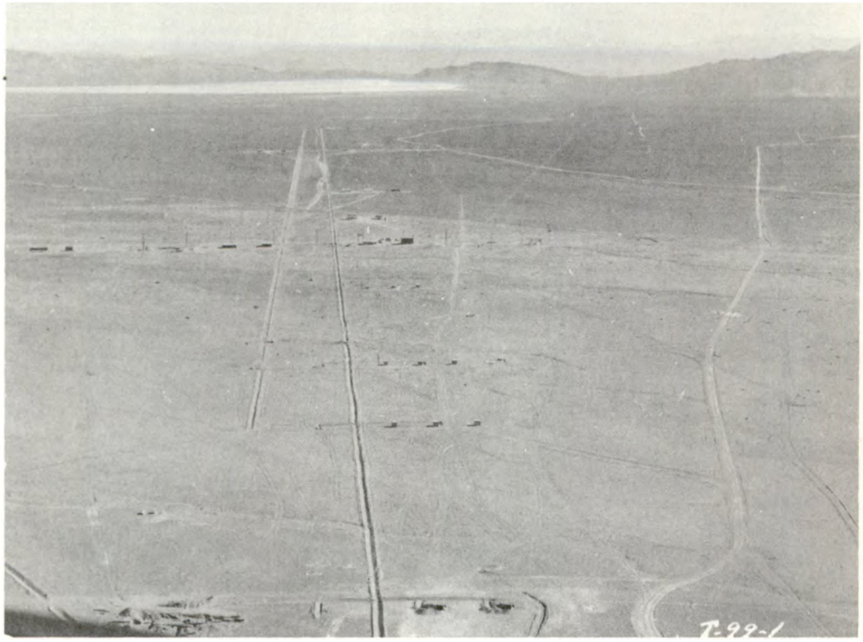

Fig. 1.1—The 4700- and 10,500-ft areas as viewed from the shot tower.

Fig. 1.2—Transmission line at the 4700-ft area.

Fig. 1.3—Substation at the 4700-ft area.

Fig. 1.4—Distribution line at the 4700-ft area.

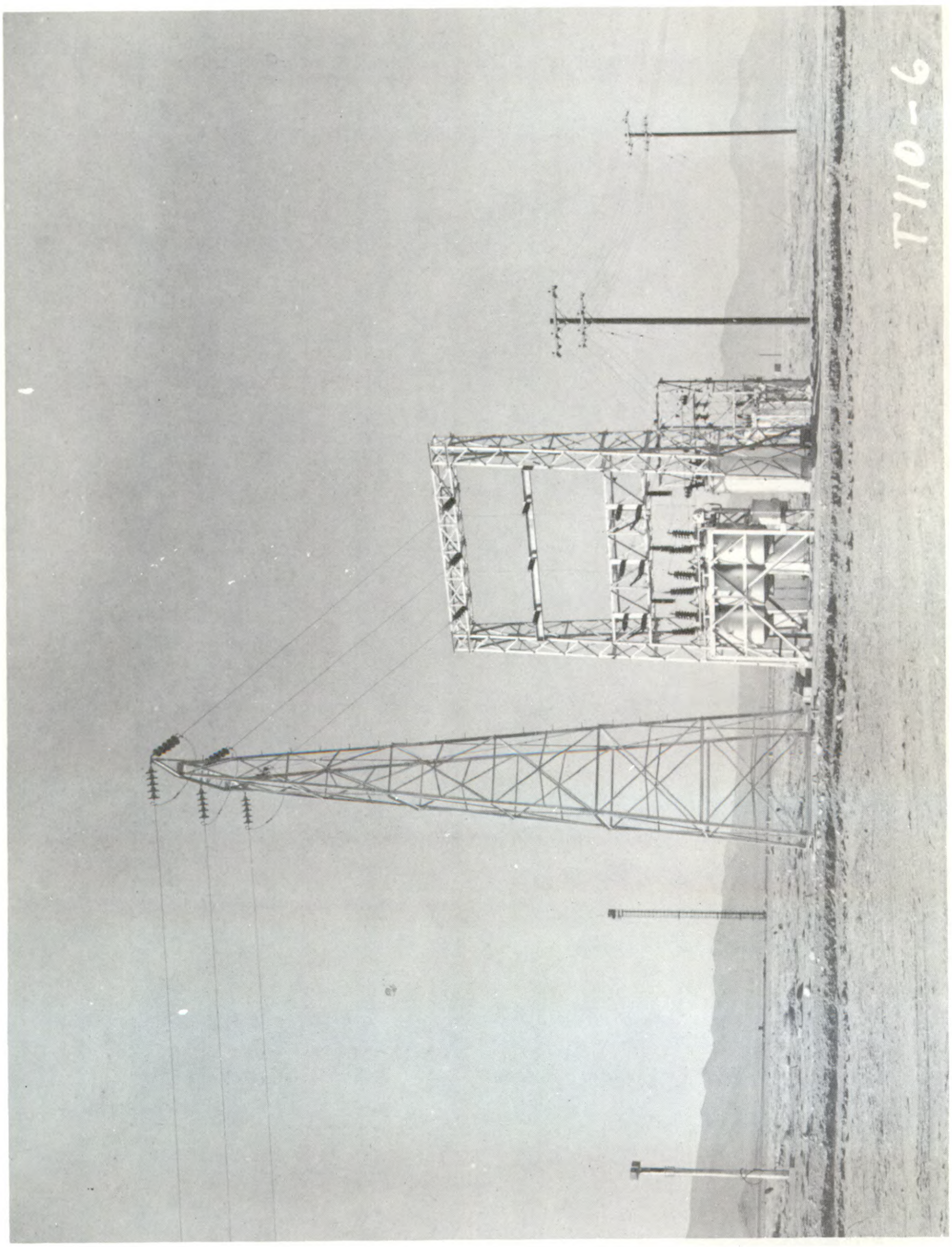

Fig. 1.5—Outdoor substation at the 4700-ft line.

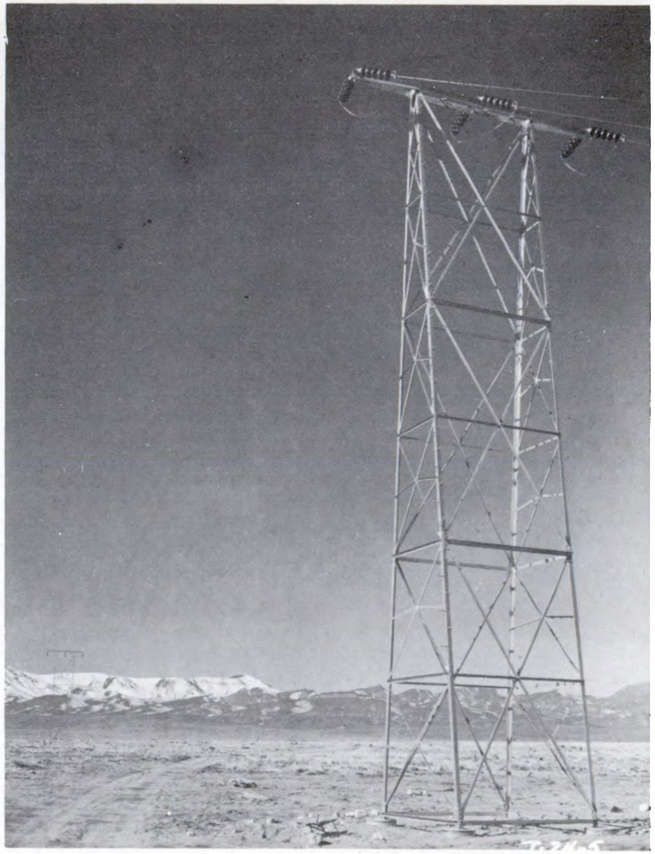

Fig. 1.6—Transmission line (69 kv).

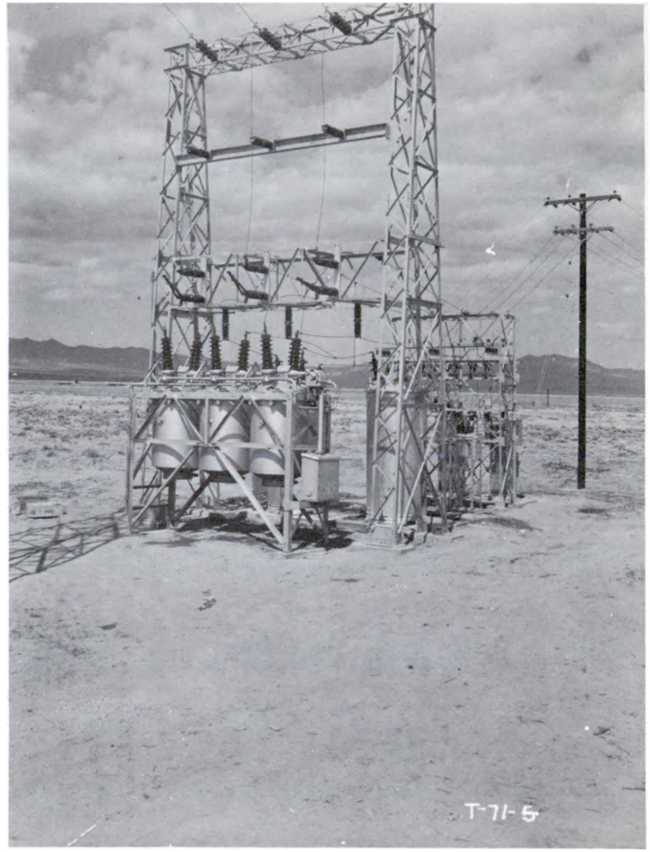

Fig. 1.7—Substation rack (69 kv).

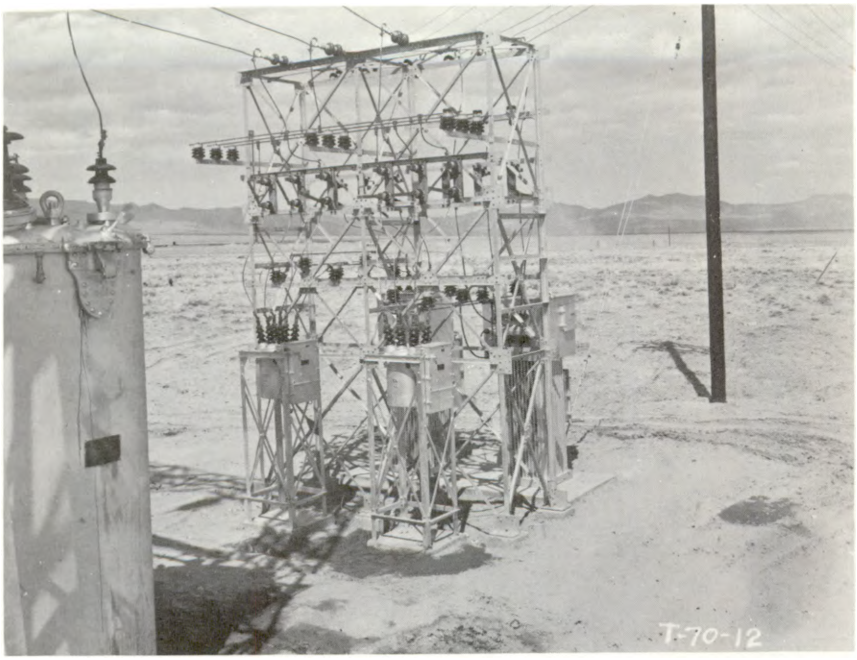

Fig. 1.8—Substation rack (4 kv).

Fig. 1.9—Distribution layout.

1.2 OBJECTIVES

The purpose of this test was to obtain information on the effect of an atomic explosion on electric supply systems. It was expected that this information would provide a sound basis for planning the rapid restoration of electric service to survival areas in the event of an atomic attack. The principal objectives of the test were to determine the following:

1. The degree and nature of damage caused by an atomic explosion to transmission lines, transformers, substations, and other equipment beyond the area of total destruction.
2. The extent to which radioactivity may affect repairs in the area.
3. The median survival range of equipment with respect to blast pressure, thermal energy, and nuclear radiation.
4. The relative ability of the individual parts of each component to withstand the effects of an atomic explosion.
5. The nature of repairs required to restore electric service to areas subjected to an atomic explosion.
6. The ability of the electric supply system, in comparison with the industrial plants and commercial and residential communities it serves, to withstand the effects of an atomic explosion.

Chapter 2

EQUIPMENT AND PRESHOT TESTS

2.1 GENERAL CONSTRUCTION

The project consisted of duplicate installations, one at 4700 ft and another at 10,500 ft from Ground Zero (GZ). Each installation consisted of a 69-kv transmission line, an outdoor substation, and two (11 and 4 kv) distribution circuits. See Fig. 2.1.

2.2 TRANSMISSION CIRCUIT

The transmission circuit consisted of a 600-ft span of three #2/0 bare copper conductors, supported by dead ends and suspension steel towers with reinforced concrete footings. The conductors were carried beyond the suspension tower and dead-ended on insulator strings connected to anchors in the ground. The insulators had a mechanical strength rating of 15,000 lb. The line hardware consisted of twist-sleeve splices and clamp type dead ends.

2.3 SUBSTATION

For the purpose of facilitating the analyses of the damage caused, the high- and low-voltage substation equipment was considered separately.

The high-voltage portion of the substation consisted of the following equipment:

1. A single-bay steel-lattice dead-end structure complete with 69-kv disconnects, insulators, and buses (Figs. 2.2 and 2.3).
2. A 73-kv 400-amp oil circuit breaker (Fig. 2.4).
3. Two 1500-kva 69/11-kv single-phase oil-filled water-cooled power transformers (Fig. 2.5).

The low-voltage portion of the substation equipment consisted of the following:

1. A steel rack with two 4-kv positions supporting two sets of 7.5-kv 400-amp disconnect switches and associated buses.
2. Two 7.5-kv 800-amp oil circuit breakers (Fig. 2.6).
3. Two 4-kv 200-amp induction voltage regulators (Fig. 2.7).
4. Three 4-kv lightning arresters.
5. Three switchboard panels complete with indicating, recording, and integrating instruments and relays, including a 12-cell lead and acid battery, all enclosed in a three-compartment metal cubicle (Fig. 2.8).

(Text continues on page 24.)

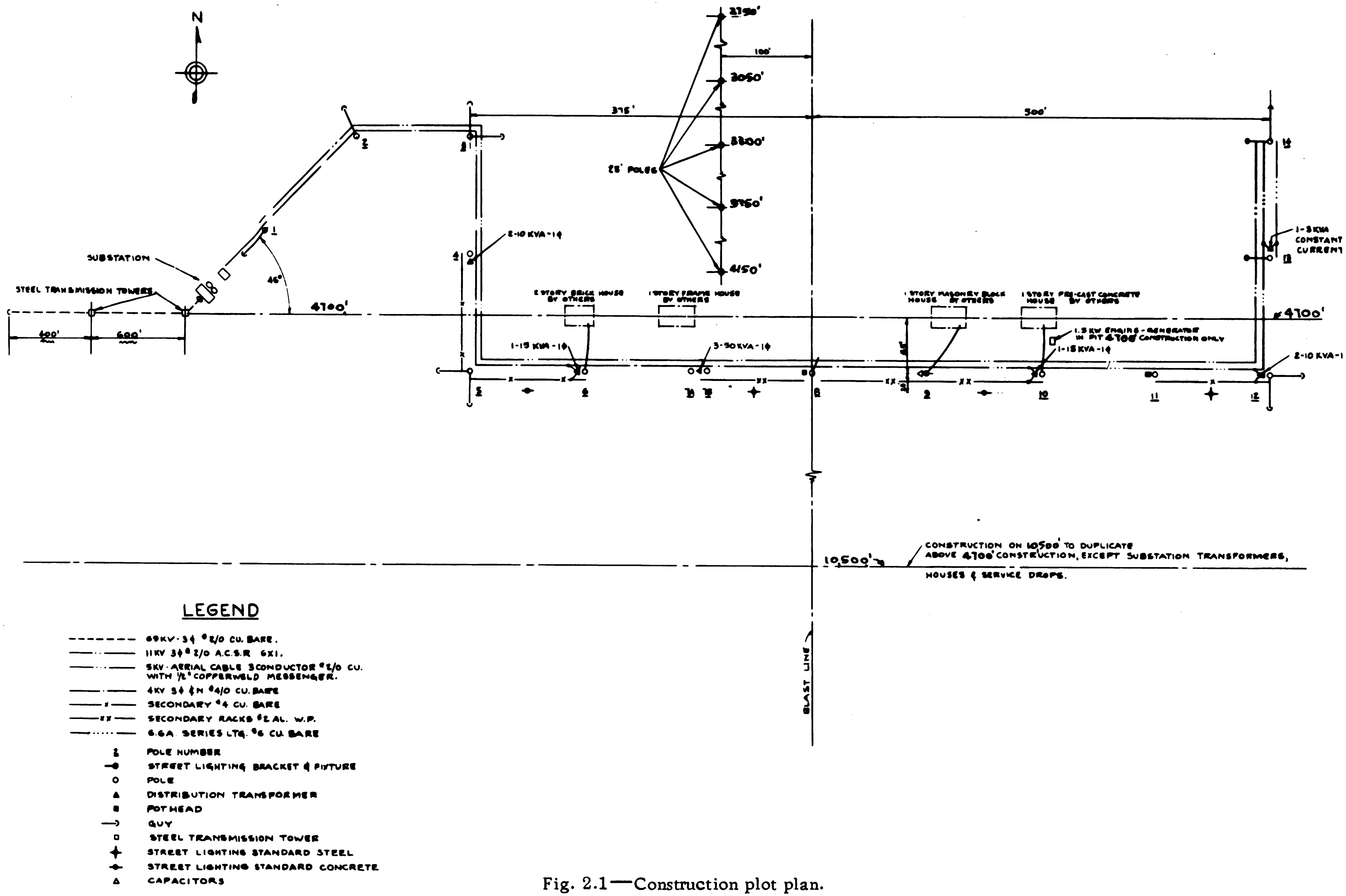

Fig. 2.1—Construction plot plan.

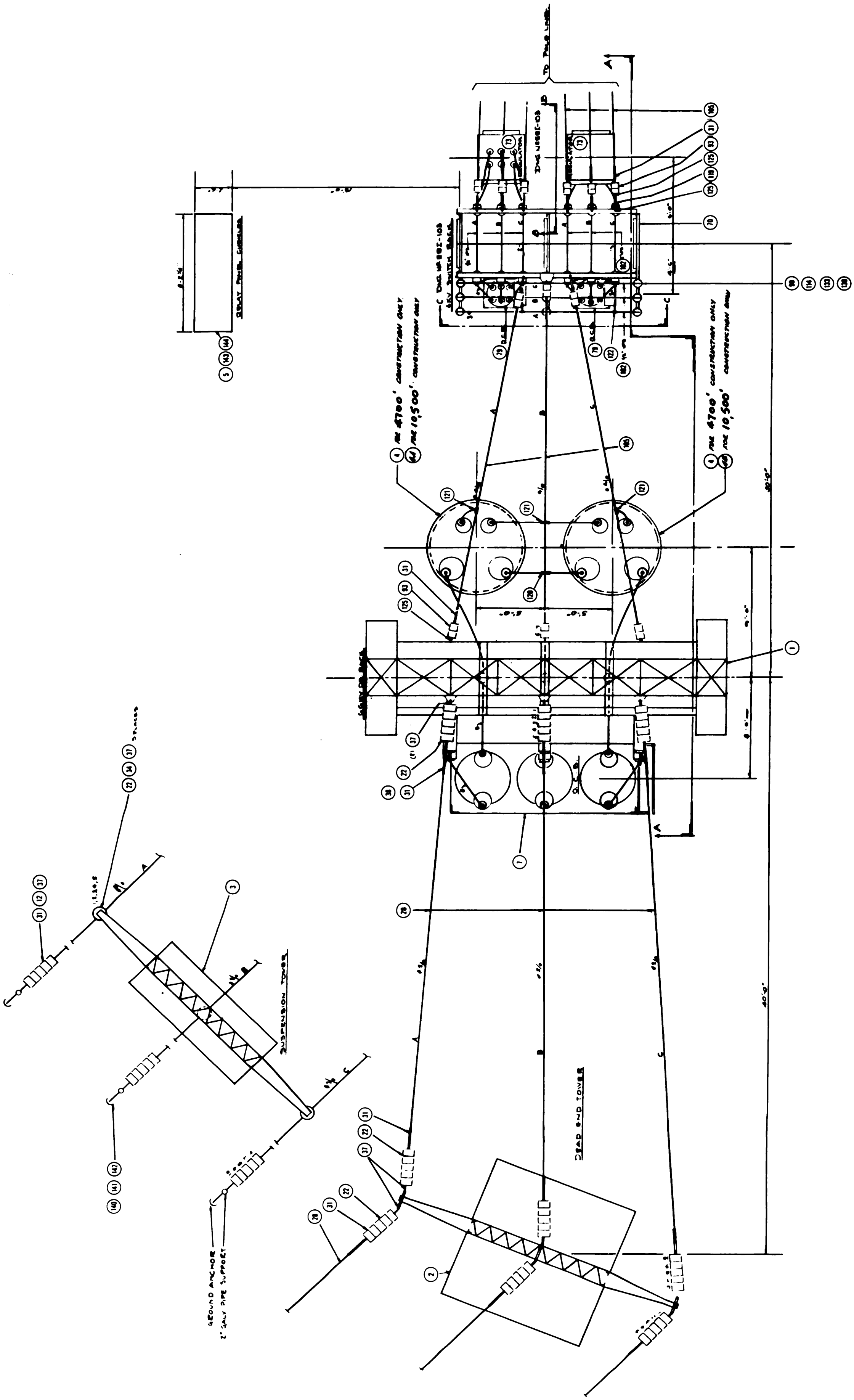

Fig. 2.2—Substation plan.

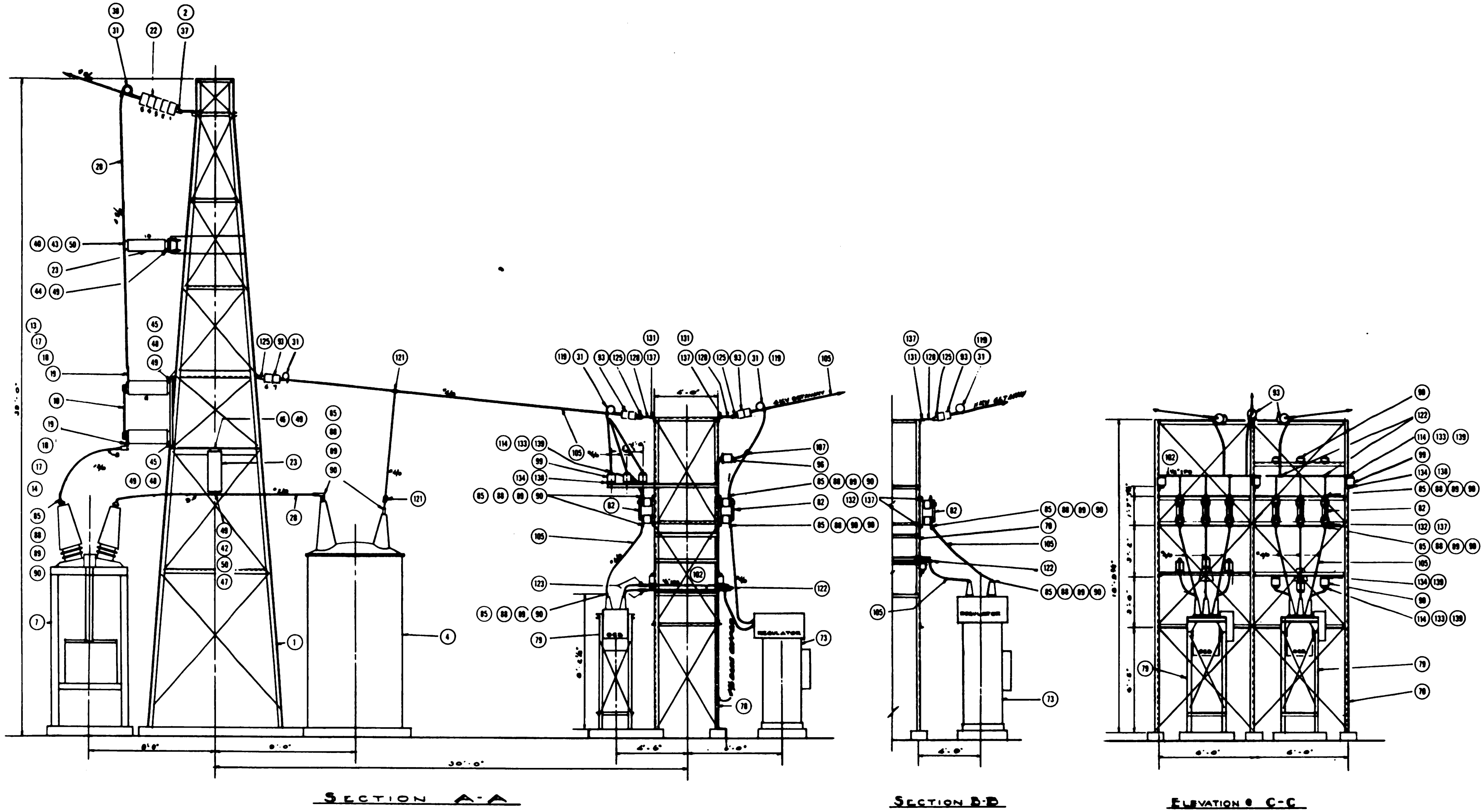

Fig. 2.3—Substation elevation.

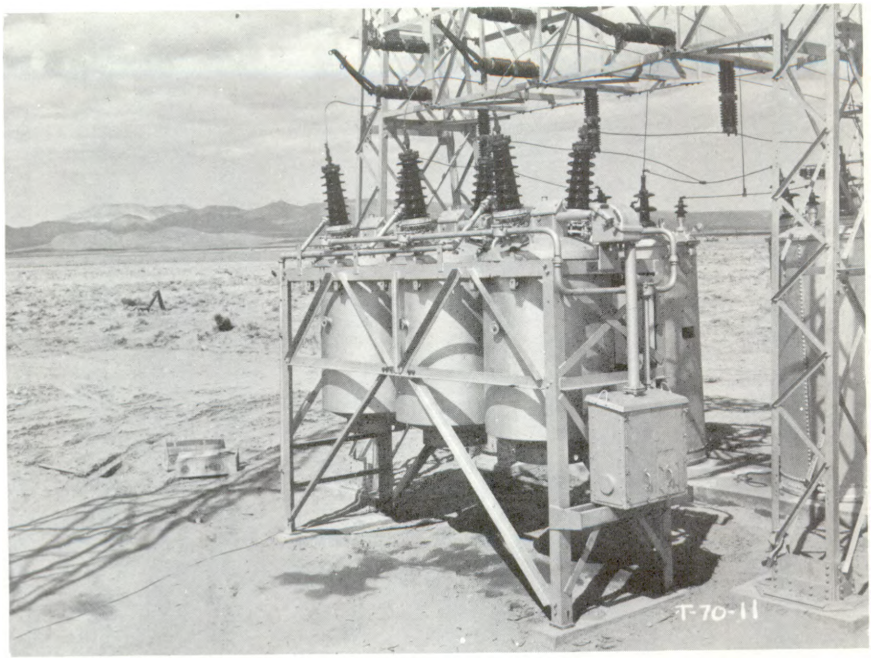

Fig. 2.4—Oil circuit breaker (73 kv).

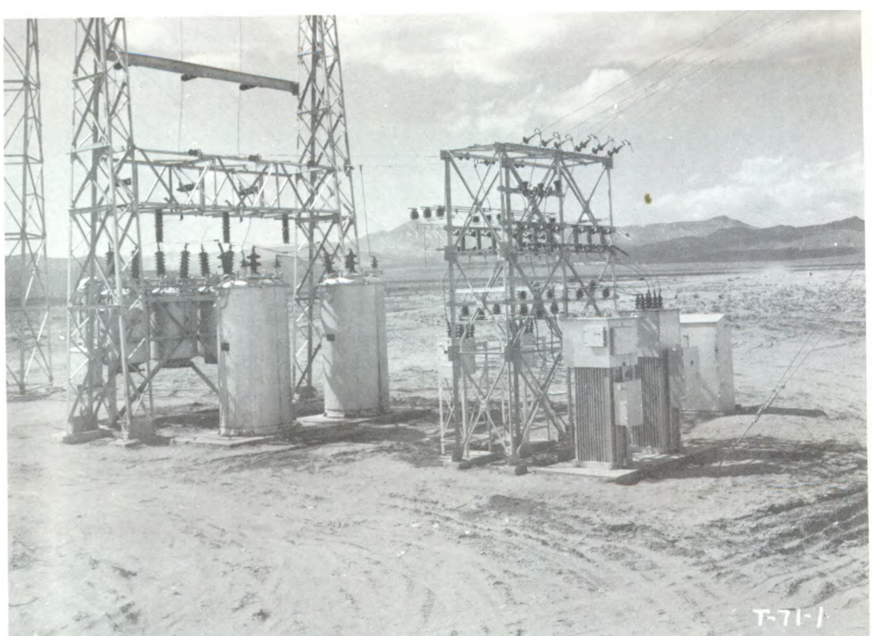

Fig. 2.5—Power transformers.

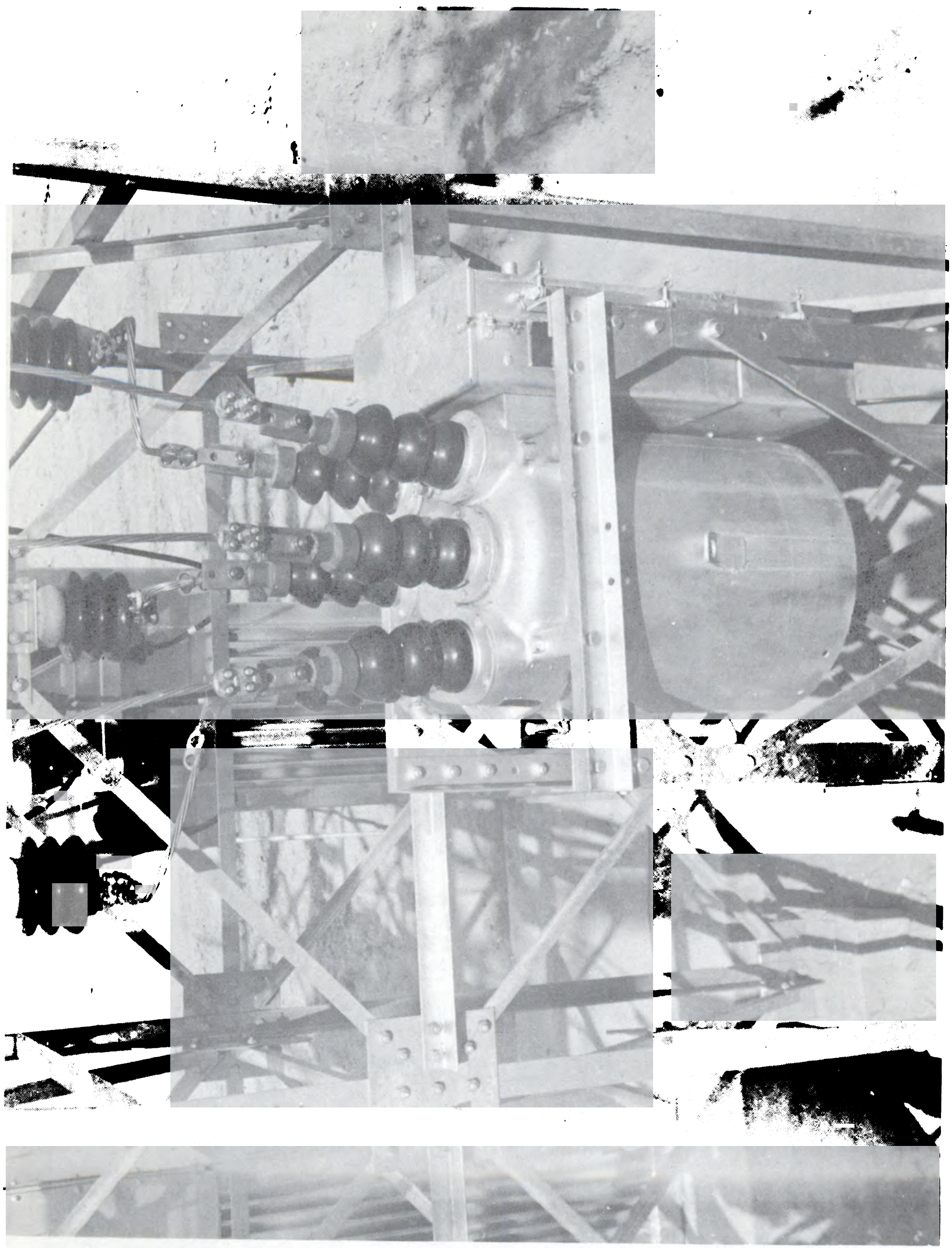

Fig. 2.6—Oil circuit breakers (7.5 kv).

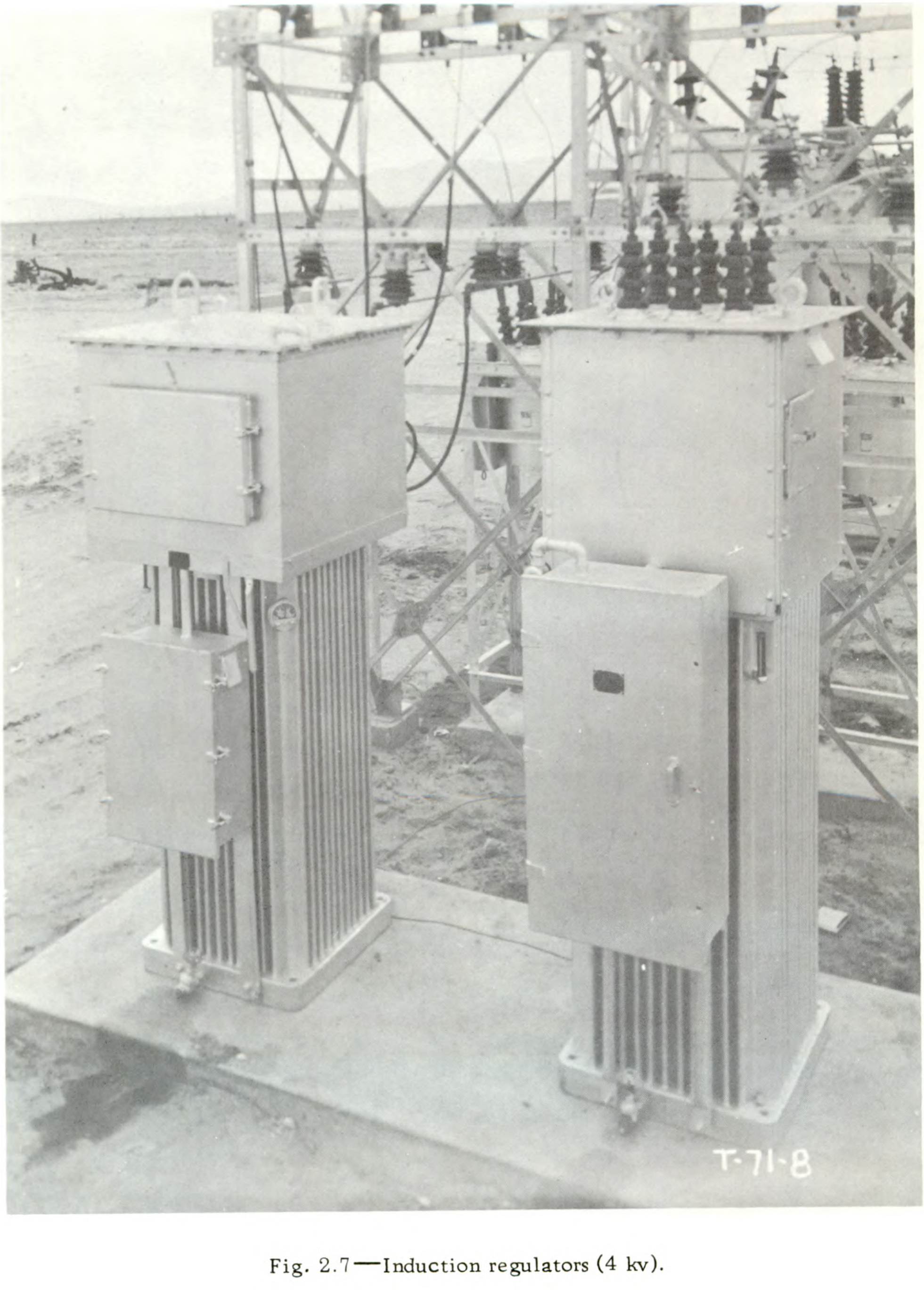

Fig. 2.7—Induction regulators (4 kv).

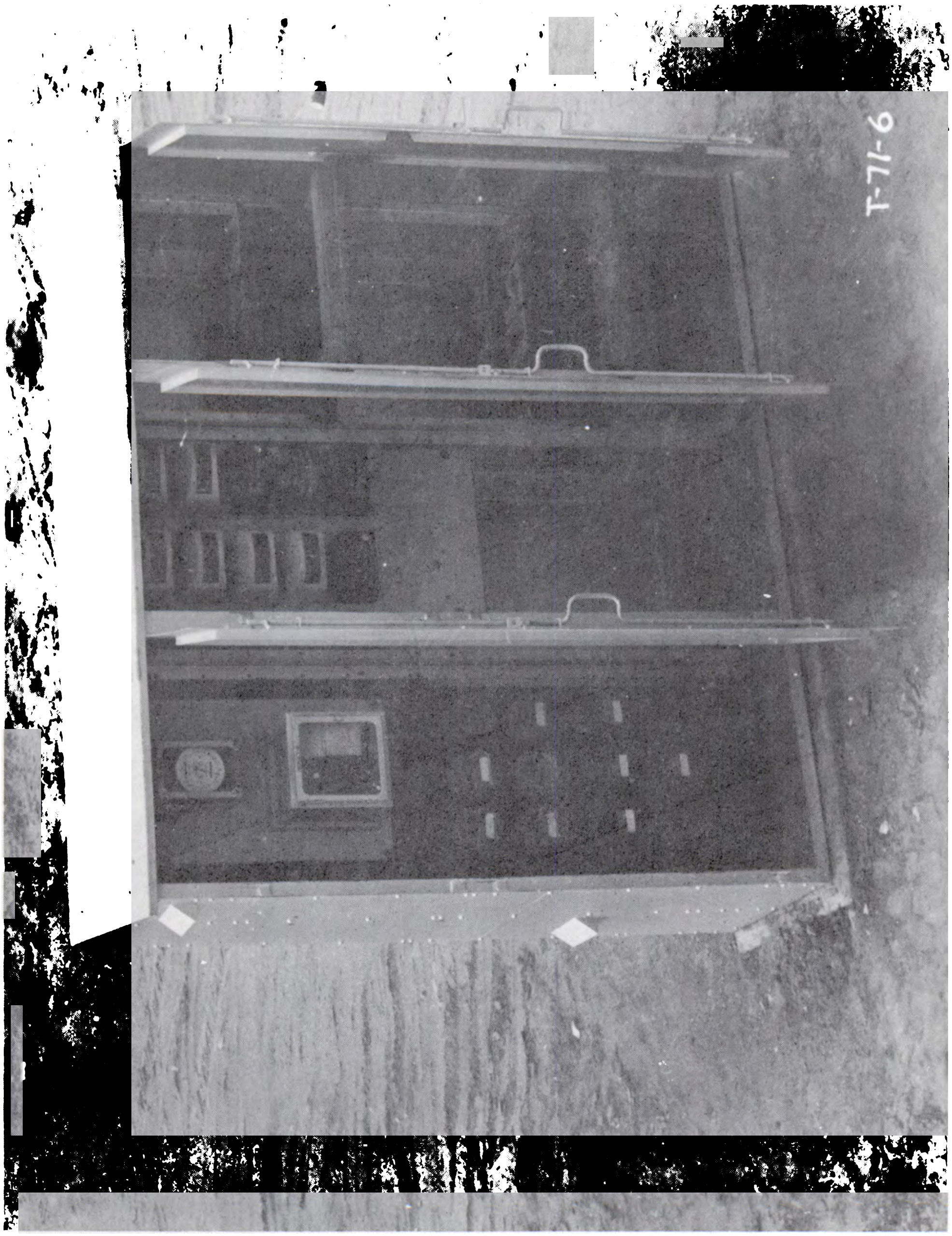

Fig. 2.8—Relay cubicle and instruments.

2.4 DISTRIBUTION

The distribution lines in each installation consisted of about one-half mile of typical wood-pole construction. The lines were oriented both radially and transversely to the line of blast. The section oriented transversely to the blast line was located along a simulated property line 50 ft behind the dwellings shown in the background of Fig. 2.9. Class 4 creosote-treated Douglas-fir poles were used in the construction of the line; they were 45 ft long and were set 6 ft in the ground. The poles were framed with crossarms to carry three circuits: an 11-kv 3-phase #2/0 ACSR circuit; a 4-kv 4-wire #4/0 copper circuit (a part of which was made up of 4-kv 3-conductor #2/0 copper prespun aerial cable with a ½-in. copper-clad messenger) with #4 bare copper secondaries along a portion of the circuit and with the remaining secondaries consisting of #2 aluminum weatherproof conductors installed on racks; and a street-light circuit consisting of #6 bare copper.

In each of the two distribution circuits (at 4700 and 10,500 ft) three 50-kva 2400/220-volt single-phase transformers were mounted on platforms (Fig. 2.10); and two 15-kva and four 10-kva 2400/230–115-volt single-phase transformers were mounted on poles.

Street lights on mast arms were mounted on two poles and were supplied by a pole-mounted constant-current transformer. Also included in the street-light construction were two steel and two concrete street-light standards.

Two potheads of the compound-filled type were pole mounted with cable and conduit installed along the poles.

An aluminum service drop was attached to one house, and copper service drops were attached to two other houses in which small loads were connected. See Fig. 2.11.

The secondary and service drops were energized from the portable generator, which was located in a pit behind one of the houses.

2.5 LINE OF POLES

A line consisting of five 25-ft creosote-treated wood poles without equipment, which were set 5 ft in the ground, was located along a blast line in which the poles were set at 2750, 3050, 3300, 3750, and 4150 ft from GZ. See Fig. 2.12.

2.6 PLACEMENT OF SERVICE EQUIPMENT

A 3-ton heavy-duty line truck that had a hydraulic boom and double winch and contained standard tools and equipment was oriented radially to the blast at 4700 ft from GZ (Fig. 2.13). A 1½-ton truck equipped with an earthboring machine was exposed broadside at 4700 ft from GZ. A 1½-ton special light-duty service truck containing tools and equipment was oriented radially to the blast line at 10,500 ft from GZ.

The effects of the explosion on this equipment are covered by Project 36.2 (Operation Teapot Report, WT-1181).

2.7 PRESHOT TESTS OF THE TRANSMISSION LINE

The following tests were made on the transmission line prior to the explosion:

1. All insulators on both the dead-end and suspension towers were individually meggered with a 100,000-megohm 5000-volt megger.

2. Each line conductor was tested at 30 kv ac to ground for 1 min on the 69-kv circuit. The 30-kv ac test to ground for the 69-kv circuit was below normal operating voltage, but it was the maximum available voltage from the portable generator and testing transformer.

3. The conductors were given a sag of 17½ ft at a temperature of 50°F, which represented a maximum tension of 3100 lb under medium loading conditions.

Fig. 2.9—Distribution circuit along the rear of the 4700-ft property line.

Fig. 2.10—Transformer bank mounted on platform.

Fig. 2.11—Typical service drops to houses.

Fig. 2.12—Stub-pole line.

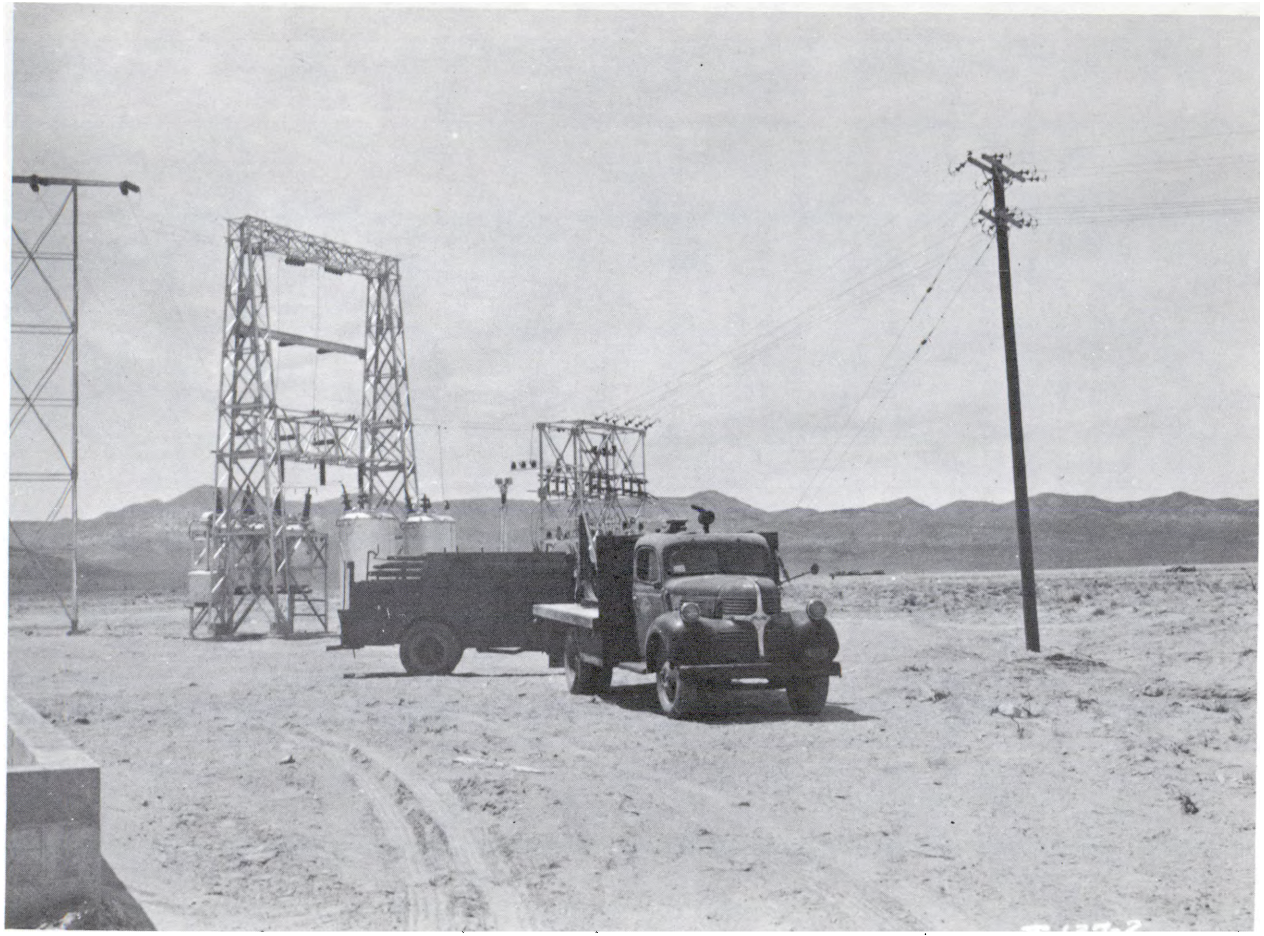

Fig. 2.13—Service vehicles at the 4700-ft area.

2.8 PRESHOT TESTS OF THE 69-KV EQUIPMENT

Tests of the 69-kv equipment included the following:

1. All insulators were meggered with the 5000-volt megger.
2. The bus work was tested at 30 kv ac to ground for 1 min.
3. The line side bushings of the oil circuit breaker were meggered at 5000 volts.
4. The 69-kv bus work, oil circuit breaker, and high-voltage side of the transformer bank were tested at 30 kv ac to ground for 1 min.
5. The low-voltage side of the transformer bank was tested at 11 kv dc to ground for 1 min.
6. The transformers were meggered at 5000 volts in the following ways: high-voltage winding to low-voltage winding, high-voltage winding to ground, and low-voltage winding to ground. Also the turn ratio between the high- and low-voltage windings was checked.
7. The oil in the transformers and oil circuit breakers was subjected to a 15-kv test.
8. The 73-kv oil circuit breaker was opened and closed both manually and electrically.

2.9 PRESHOT TESTS OF THE 4-KV EQUIPMENT

Three tests were applied to the 4-kv equipment. They are listed as follows:

1. The 4-kv bus work and insulators were meggered, and the high potential was tested to ground at 5-kv dc for 1 min.
2. The voltage regulators were meggered, and the high potential was tested at 11 kv ac for 1 min (neutral was disconnected). They were also operated electrically to the full raise and lower positions.
3. The 7.5-kv oil circuit breakers were meggered, and the high potential was tested to ground at 5 kv dc for 1 min. They were also opened and closed both manually and electrically.

2.10 PRESHOT TESTS OF DISTRIBUTION INSTALLATIONS

The following tests were made on the distribution installations:

1. All 11-kv insulators were meggered at 5000 volts.
2. The high potential of the 11-kv circuit was tested between phases at 22 kv dc for 1 min.
3. The 4-kv circuit, including all distribution transformers, was energized at 4 kv between phases and at a 2400-volt phase to ground for 1 min.
4. All distribution transformers were meggered at 5000 volts between the high- and low-voltage windings and from each winding to ground.
5. All relays were tested and found to operate satisfactorily at their minimum trip values.
6. All instruments were given an operation test to see that they worked freely while voltage and current were being applied.

The yield of Apple II was approximately 50 per cent greater than nominal (a nominal atomic bomb has an energy release equivalent to 20 kilotons of TNT).

Chapter 3

OBSERVATIONS, EFFECTS, AND CONCLUSIONS

3.1 GENERAL

The Apple II Shot, in which Project 35.1 participated, took place on May 5, 1955, at the Nevada Test Site (NTS). The atomic device was mounted on a 500-ft tower, the yield of which was of the order of 30 kt, which was 50% greater than nominal.

The overpressure at the 4700- and 10,500-ft lines was of the order of 5 psi and 2 psi, respectively; and the thermal radiation effect at the 4700-ft line was expected to be approximately 20 cal/cm^2.

The results of the initial radioactivity measurements for the project were not available for this report. However, by field monitor instrument readings, the radiation intensity at the 4700-ft line was approximately 24 mr/hr about 3 hr after the shot.

With the approval of the Safety and Physical Damage Team following their inspection of the test area, the first group of industrial representatives went into the 4700-ft test area less than 3 hr after the shot, which was shortly after R-hour was announced.

3.2 OBSERVATIONS

3.2.1 Installations at 4700 Ft from GZ

The damage to the electric system at the 4700-ft line was moderate. The type of damage appeared similar to that caused by severe windstorms and was due to the blast effect and missiles, rather than to the thermal or radiation effects of the explosion.

The suspension type transmission tower had collapsed and was lying on the ground.

The substation had survived the blast with minor damage to its essential components. The metal cubicle itself, housing the meters and relays, was heavily damaged. However, this cubicle and its contents were not essential to the emergency operation of the system. The 4-kv regulators had been shifted on the concrete pad, resulting in separation of the electrical connections to the bus. The substation was in sufficiently sound condition to permit reenergizing on a nonautomatic basis.

The distribution line would have required considerable rebuilding in that four out of the fifteen wooden poles had been broken; several distribution transformers had fallen; and secondary wires and service drops were down. This damage was of the type that could be repaired in a reasonably short time with materials normally carried in stock by electric-utility companies.

Both the steel and concrete street-light standards were undamaged; however, the luminares were all broken off by swinging conductors, except the luminare between poles 5 and 6, which was broken by the blast effect or missiles. The wood-pole-mounted mast arm type units were undamaged except for a moderate bending of the mast arm itself. The streamlined elliptical luminares were all intact.

A typical urban brick house to which a service drop had been connected along this line was demolished. Typical single-story reinforced masonry block and precast concrete houses, whose service drops were disconnected by the blast, sustained only moderate damage, mostly to windows, doors, and furnishings.

3.2.2 Installations at Other Distances from GZ

Of the five poles, without equipment, located along the blast line, the two nearest GZ (at 2750 and 3050 ft) were broken off at the ground line.

At the 10,500-ft installation, the electric system was intact with no damage except for a slight denting of a panel door on the relay and meter cubicle. The dwellings at this location to which service drops had been connected suffered severe damage to windows and doors with some interior damage as well. Some houses had been structurally strained but in all cases appeared safe enough for immediate occupancy.

3.3 RESULTS

This section deals entirely with the electrical installation located in the 4700-ft area (Figs. 3.1 to 3.3) since there was no damage to electrical facilities at the 10,500-ft area, as determined by observations and tests.

3.3.1 Transmission Line

The only damage was to the suspension tower, which was blown over in a direction transverse to the transmission line (Fig. 3.4). The leg angles bent at the splice plates, which fastened them to the anchor stubs. The two leg members on the side of the tower away from the shot broke about 8 ft above the ground at a point where there were two ½-in. holes side by side on the 3-in. angle member. One insulator string was broken due to impact with the ground. The line conductors, splices, and hardware were undamaged.

3.3.2 Substation

The steel dead-end structure supporting the 69-kv insulators, disconnects, and buses received minor structural damage (Fig. 3.5) in that two leg angles were slightly buckled at a point 3 ft above the foundation where several unused bolt holes were located.

The 73-kv oil circuit breaker remained in the closed position and was undamaged. It later withstood a 30-kv a-c high-potential test to ground, being operated both manually and electrically.

All insulators, disconnect switches, buses, and hardware were tested identically to preshot tests and were considered to be undamaged.

The two 1500-kva 69/11-kv transformers were undamaged and were not moved on the foundation pad. They later withstood a 30-kv a-c high-potential test to ground. The turn ratio between windings tested satisfactorily; and when meggered they gave the same values as was found in the preshot tests. The paint on the side of the case facing the blast was slightly blistered (Fig. 3.6). Neither the temperature nor the oil-level gauges were damaged.

The steel rack with the 4-kv equipment, which included several 7.5-kv 400-amp disconnect switches, two 7.5-kv 800-amp circuit breakers, and several associated buses, was undamaged, as determined by observations and repeated high-potential, megger, and operational tests that were identical to preshot tests.

The two 4-kv 200-amp induction regulators were shifted on the foundation pad sufficiently to break electrical connections to the bus. In addition, the square flat-surfaced housing at the top of one regulator was dished on all four faces (Fig. 3.7). The flat-faced temperature-gauge glass was broken. The cylindrical oil-level gauge was not broken.

The regulators were tested and found to be electrically operative, but the raise and lower mechanism on one regulator was temporarily jammed. After approximately four operations of the raise and lower contactor, the mechanism was moving freely and was operating efficiently.

Fig. 3.1—Postshot view of the transmission line at the 4700-ft area.

Fig. 3.2—Postshot view of the substation at the 4700-ft line.

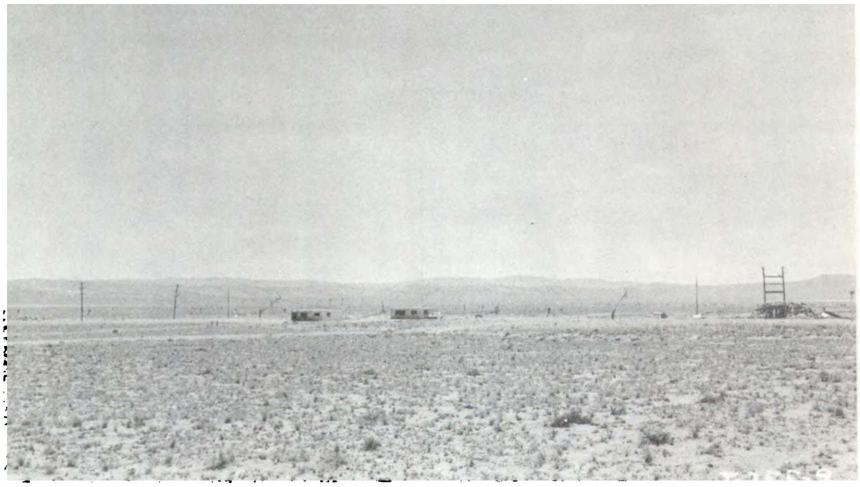

Fig. 3.3—Postshot view of the distribution circuit at the 4700-ft line.

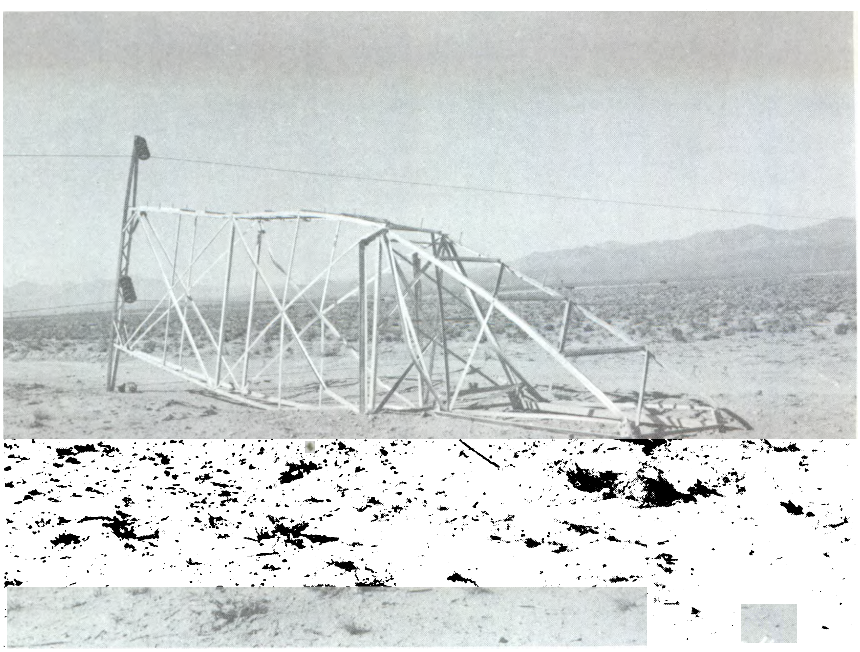

Fig. 3.4—Structural failure of the suspension tower at the 4700-ft line.

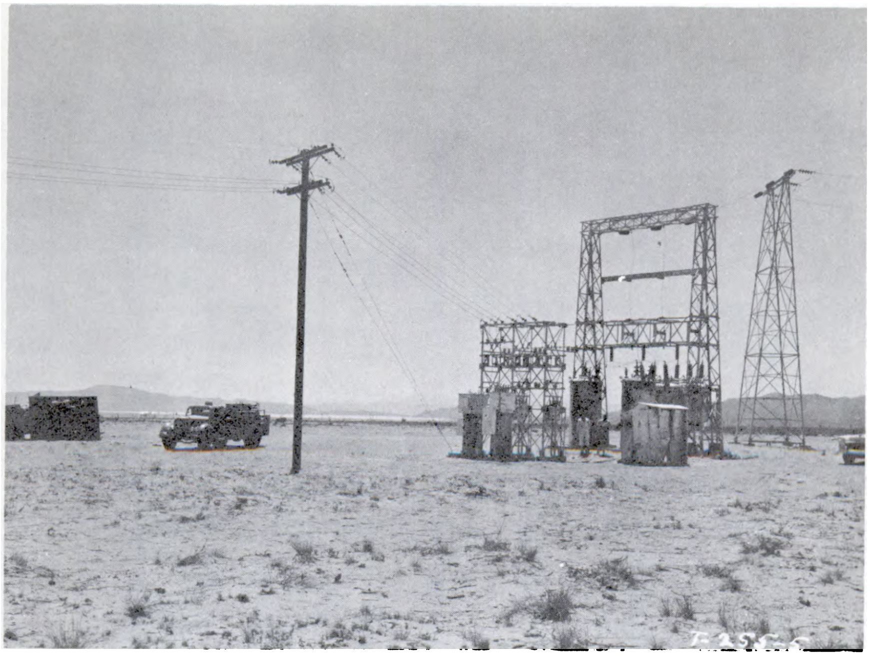

Fig. 3.5—Postshot view of the substation at the 4700-ft line.

Fig. 3.6—Thermal effect on the power transformer at the 4700-ft line.

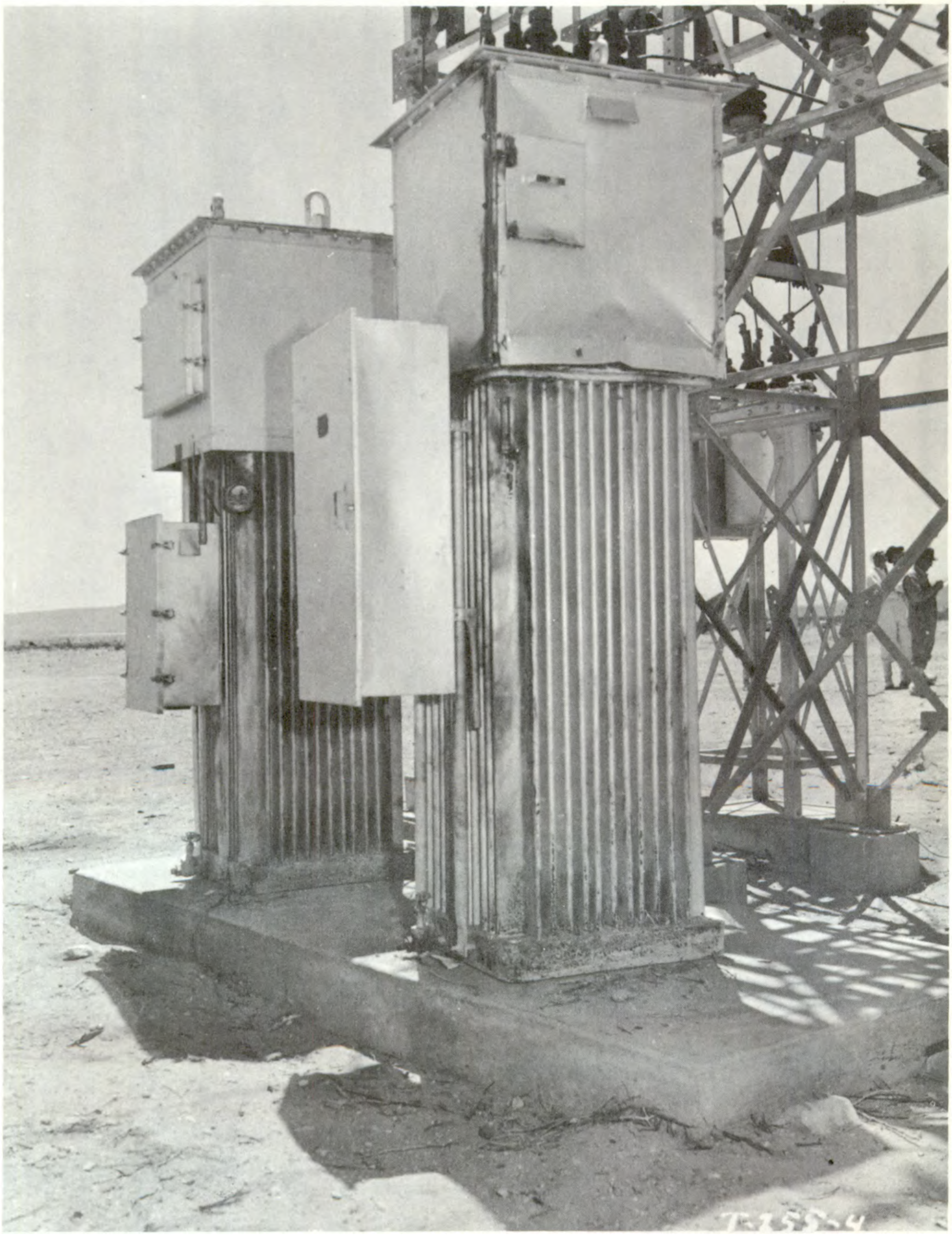

Fig. 3.7—Displacement of induction regulator and thermal effect on it at 4700 ft from GZ.

The three-compartment metal cubicle that housed meters, batteries, and instruments was severely damaged. The foundation pad to which this structure was bolted was noticeably tilted. See Fig. 3.8.

The battery cells were completely destroyed. All the glass cells were broken, acid was spilled over the ground, and most plates (both positive and negative) were damaged beyond repair.

The relays, instruments, and meters were tested identically to preshot tests and were found to be undamaged except for a broken cover glass on the recording wattmeter.

3.3.3 Distribution Circuit

The distribution system sustained light to moderate damage. Of the poles in 14 positions, 5 were not damaged, 3 were very slightly damaged (to the extent of broken insulator pins on the 4-kv circuit only), 2 were extensively damaged, and 4 were down. No 11-kv metal insulator pins failed; and, except for down poles, the 11-kv circuit could have been reenergized. Slight scorching occurred to poles and crossarms. See Figs. 3.9 and 3.10.

All the primary conductors (both aluminum and copper) and the aerial cable were unbroken even in the area of heavy damage to crossarms and poles. All the pole anchors and guys remained intact. The two 10-kva transformers installed on a line crossarm and connected in open delta were not displaced although they were subject to the direct effects of the blast. The two pothead installations, located on poles that were broken, were unharmed. The risers were bent but not broken. All the arresters and fused cutouts were undamaged and firmly in place where arms were not broken.

Pole 1 sustained one missing 11-kv insulator, but the pin was still in place in the crossarm. Poles 2 and 3 were undamaged. Pole 4 had two 4-kv wood insulator pins sheared and one pulled out of crossarm. The two 10-kva transformers were in place and undamaged although the crossarm on which they were hung was badly cracked. See Fig. 3.11. Pole 5 was undamaged. On pole 6 the 11-kv circuit was intact, but the 4-kv and secondary crossarms were splintered, apparently by house missiles. The 15-kva transformer was knocked to the ground at a distance of 36 ft from the pole. See Fig. 3.12. On poles 7A and 7B, the 11-kv circuit was intact, but four of the 4-kv wood insulator pins sheared, and two others pulled out. The crossarms were undamaged. The poles were displaced 4 in. at ground level and were leaning away from the blast due to the weight of adjacent down poles. See Figs. 3.13 and 3.14. The three 50-kva platform-supported transformers were blown to the ground, apparently by blast and missiles from the houses. See Fig. 3.15. The crossarms were undamaged. Pole 8 broke about 8 ft above ground level. The top portion leaned 60° from the vertical. One wood pin sheared on a 4-kv crossarm in the 4-kv circuit. The pothead was undamaged; the riser pipe bent, but the cable was undamaged. Secondaries between poles 7b and 8 snapped at the insulators on pole 8. See Fig. 3.16. Pole 9 broke at ground level, but the 11-kv circuit was intact. No damage was noted to the crossarms, capacitors, or insulators. The aerial cable was unbroken from pole 9 to pole 14. See Fig. 3.17. Pole 10 broke 1 ft below ground level. A 15-kva transformer was knocked to the ground and broken. The top of pole was split. The 11-kv crossarm was not broken but was separated from the pole. One 11-kv insulator was broken. The crossarm supporting the aerial cable was separated from the pole but was held on by the braces. One 11-kv conductor (#2/0 ACSR) was frayed and cut in half by the radio-tower guy wire on which it fell. See Figs. 3.18 and 3.19. Pole 11 was broken 8 ft above the ground. One 11-kv insulator was broken. The riser pipe was bent, but the pothead and the aerial cable were not damaged. See Fig. 3.20. Pole 12 was undamaged; the two 10-kva transformers remained in place and were not damaged. The pole bent about 5° in the direction of the downed poles. Pole 13 had one 11-kv insulator missing. The mast arm of the luminare was deflected about 10°. The globes, which were elliptically shaped, were not broken. Pole 14 was not damaged. The mast arm of the luminare was deflected about 10°, but the elliptical globes were not broken.

(Text continues on page 44.)

Fig. 3.8—Damage to the relay cubicle at 4700 ft from GZ.

Fig. 3.9—Failure of the distribution circuit at the rear of the 4700-ft property line.

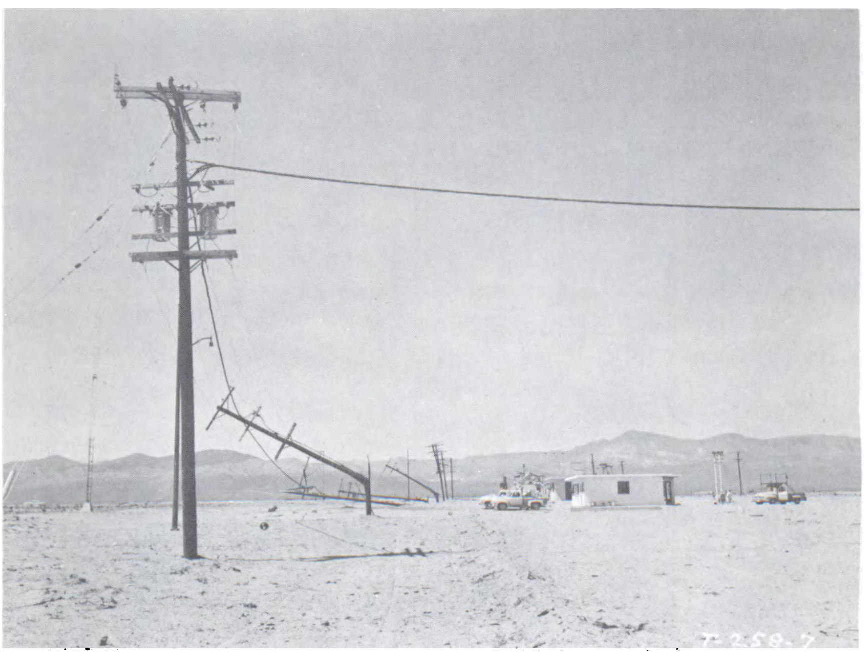

Fig. 3.10—Damage to pole 12 at 4700 ft from GZ.

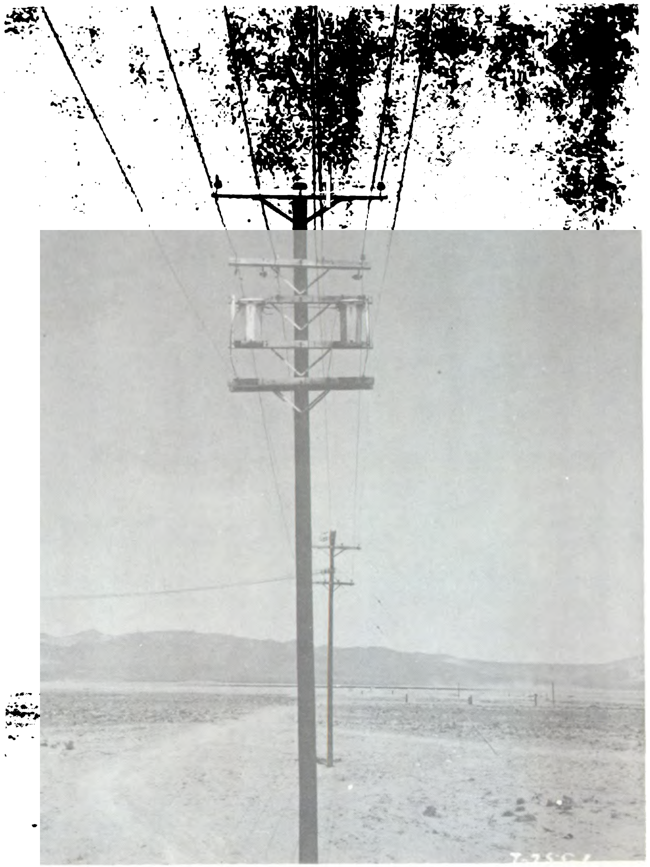

Fig. 3.11—Damage to pole 4 at the 4700-ft line.

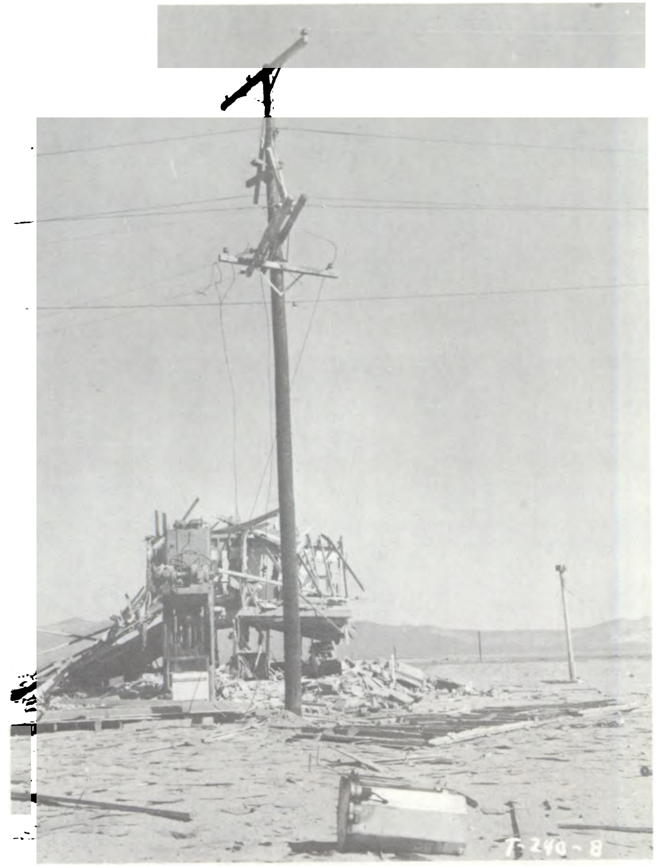

Fig. 3.12—Damage to pole 6 and transformer at the 4700-ft line.

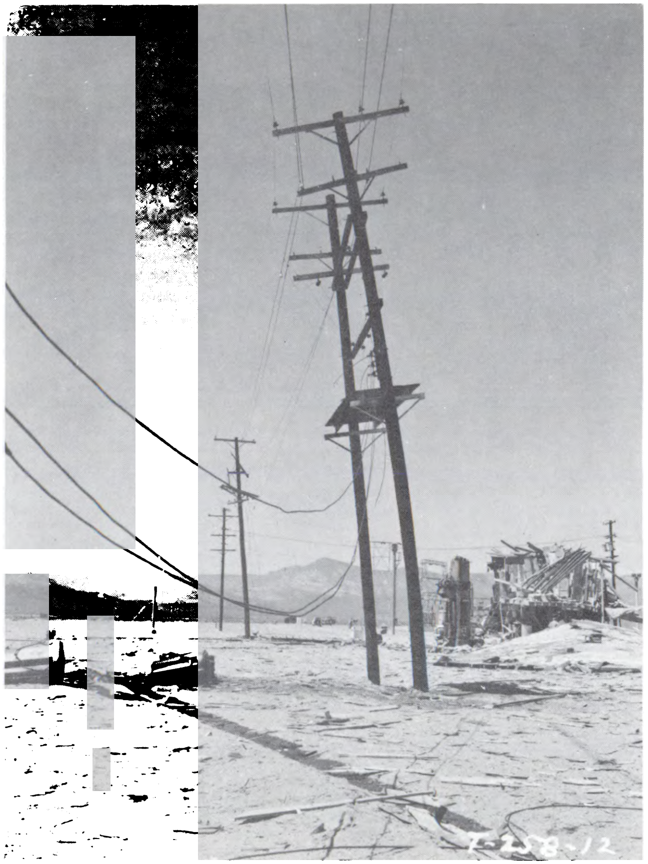

Fig. 3.13—Damage to poles 7-A and 7-B at the 4700-ft line.

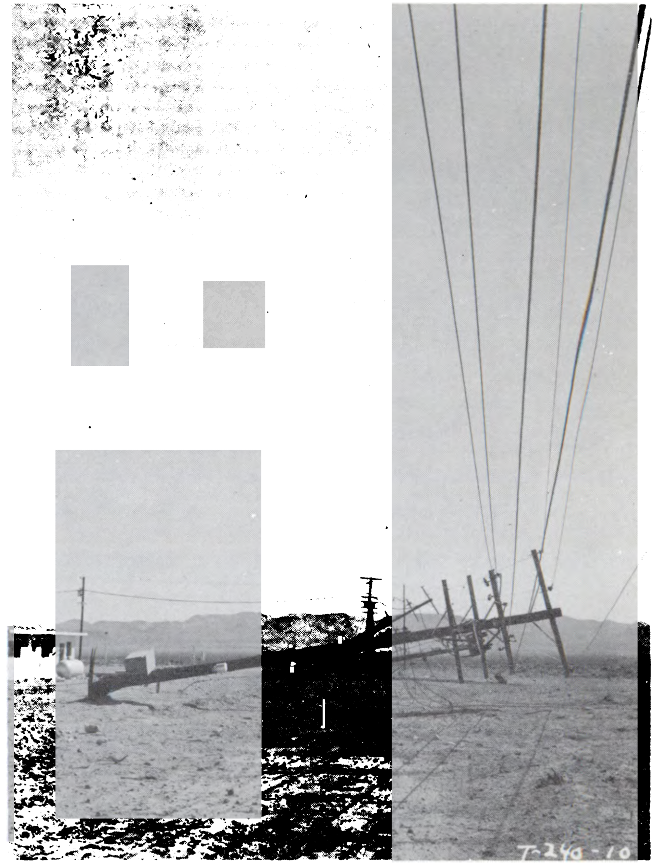

Fig. 3.14—Damage to distribution poles at the 4700-ft line.

Fig. 3.15—Damage to transformers mounted on platforms at the 4700-ft line.

Fig. 3.16—Damage to pole 8 at the 4700-ft line.

Fig. 3.17—Damage to pole 9 at the 4700-ft line.

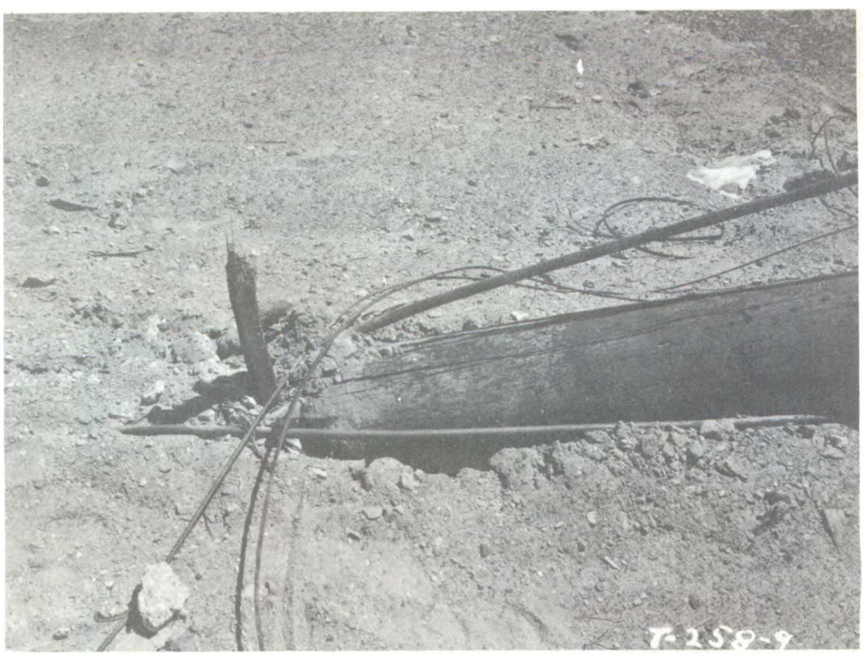

Fig. 3.18—Damage to pole 10 at the 4700-ft line.

Fig. 3.19—Damage to transformer at the 4700-ft line.

Fig. 3.20—Damage to pole 11 at the 4700-ft line.

3.3.4 Conductors

Three conductors used at the 4700-ft line were tested postshot to values of more than their manufacturers' guarantee. This leaves no doubt that all the conductors could have been restrung. A description of the three conductors tested is as follows:

1. A 2/0 copper 7-strand conductor, used on the 69-kv circuit.
2. A 4/0 copper 7-strand conductor, used on the 4-kv circuit.
3. A 2/0 ASCR 6X1 conductor, used on the 11-kv circuit.

3.3.5 Line of Poles

The two most forward poles in the line without equipment, which were located at 2750 and 3050 ft from GZ, broke off at the ground level. The others were intact. A slight charring was noted on these poles, but it was to a lesser degree than on the poles at the 4700-ft line.

3.3.6 Service Equipment

The heavy crew truck, exposed in Project 36.2, sustained broken windows and a bent hood, but its equipment was not damaged.

The truck that was equipped with an earthboring machine (also exposed in Project 36.2) tipped over, sliding the boring machine to the ground (Fig. 3.21).

Fig. 3.21 — Damage to service vehicles at the 4700-ft line.